ARMY RESEARCH LABORATORY

# A Tool for Calculating the Center of Mass and Moment of Inertia of Small Arms Weapons

by Michael E. LaFiandra

ARL-TR-4517 July 2008

## NOTICES

### Disclaimers

# Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5425

**ARL-TR-4517** **July 2008**


# A Tool for Calculating the Center of Mass and Moment of Inertia of Small Arms Weapons


**Michael E. LaFiandra**
**Human Research and Engineering Directorate, ARL**

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE (DD-MM-YYYY) | 2. REPORT TYPE | 3. DATES COVERED (From - To) |
|---|---|---|
| July 2008 | Final | August 2007–December 2007 |

**4. TITLE AND SUBTITLE**
A Tool for Calculating the Center of Mass and Moment of Inertia of Small Arms Weapons

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Michael E. LaFiandra

**5d. PROJECT NUMBER**
62716AH70

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
U.S. Army Research Laboratory
ATTN: AMSRD-ARL-HR-SB
Aberdeen Proving Ground, MD 21005-5425

**8. PERFORMING ORGANIZATION REPORT NUMBER**
ARL-TR-4517

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

The center of mass (COM) of a body or segment is the point about which the mass of the body or segment is evenly distributed. Moment of inertia (MOI) is the measure of a segment or object's resistance to changes in angular velocity. Mass properties, such as COM, MOI, and mass, allow for characterization of objects and for an easy comparison of the effects of force and torque on the dynamics of the object.

This report describes and demonstrates the use of a software tool designed to calculate the effect of weight added to a weapon on the weapon's mass properties (COM, MOI, and total mass). The weapon COM tool was developed in support of the North Atlantic Treaty Organization (NATO) Research and Technology Organization (RTO) Systems Concepts and Integration (SCI)-178 RTO Task Group (RTG)-043 task group on dismounted Soldier system weapon systems inter-operability. The NATO SCI-178 RTG-043 task group has identified assault rifle weapon weight and COM as a primary research area.

**15. SUBJECT TERMS**
biomechanics, center of mass, moment of inertia, small arms

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON Michael E. LaFiandra |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER (Include area code) |
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UL | 26 | 410-278-5962 |

**Standard Form 298 (Rev. 8/98)**
**Prescribed by ANSI Std. Z39.18**

# Contents

## List of Figures

# Executive Summary

This report describes and demonstrates the use of a software tool designed to calculate the effect of weight added to a weapon on the weapon's mass properties (center of mass [COM], moment of inertia [MOI], and total mass). The Weapon COM Tool was developed in support of the North Atlantic Treaty Organization (NATO) Research and Technology Organization (RTO) Systems Concepts and Integration (SCI)-178 RTO Task Group (RTG)-043 task group on dismounted Soldier system weapon systems interoperability. The NATO SCI-178 RTO-043 task group has identified assault rifle weapon weight and COM as a primary research area.

The COM of a body or segment is the point about which the mass of the body or segment is evenly distributed. MOI is measure of a segment's or object's resistance to changes in angular velocity. Mass properties, such as COM, MOI, and mass, allow for characterization of various weapons and allow for an easy comparison between weapon systems.

The Weapon COM Tool is based on fundamental equations found in many physics or biomechanics texts[1,2] and can determine the effects of as many as four added weights. The added weight can be accoutrements (such as new sights), additional weapons (such as an M203 grenade launcher), or any other object that is mounted to the weapon.

This report documents the development of a tool for calculating the mass properties of a weapon and subsequently does not report the results of a specific analysis or evaluation.

[1]Winter, D. *Biomechanics and Motor Control of Human Movement (2nd ed.)*; New York: John Wiley and Sons, 1990.
[2]Hamill, J.; Knutzen, K. *Biomechanical Basis of Human Movement (1 ed.)*; Baltimore: Williams & Wilkins, 1995.

INTENTIONALLY LEFT BLANK

# 1. Project Background

This project is in support of the North Atlantic Treaty Organization (NATO) Research and Technology Organization (RTO) Systems Concepts and Integration (SCI)-178 RTO Task Group (RTG)-043 task group on dismounted Soldier system weapon systems interoperability. This group was created to advance developments in the area of integration and interoperability of dismounted Soldier system weapon systems. The task group considers the technical issues, human factors, and power requirements associated with infantry weapons that are components of dismounted Soldier systems. Currently, there is a large variety of assault weapon types (M4, M16, G3, FAL, and Steyr), designs (traditional, bullpup, etc.), firing mechanism controls, and weights. The NATO SCI-178 RTO-043 task group has identified assault rifle weapon weight and center of mass (COM) as a primary research area.

Knowledge of the location of the COM of a body allows a distributed mass to be represented as a single location.[1] The COM of a body or segment is the point about which the mass of the body or segment is evenly distributed.[2] In order to cause a net acceleration an object, force needs to be applied to every particle of mass that compromises the object. The net force exerted on a rigid body object is represented as a single resultant force,[3] and because the COM is the point about which the mass of an object is evenly distributed, the COM is the point at which this resultant force is applied.

The moment of inertia (MOI) is also important in characterizing objects. While COM allows for a distributed mass to be represented as a single location, MOI provides information about the distribution of mass. Additionally, the amount of mass an object has is a measure of the object's resistance to changes in linear velocity, whereas MOI is measure of a segment's or object's resistance to changes in angular velocity.[1] MOI can be defined around any point (or axis); however, in many cases, MOI is defined relative to the COM. Objects with the same COM can have vastly different MOIs (figure 1). Additionally, the MOI of an object around one point or axis will be different than the MOI of the same object around a different point or axis.

Mass properties, such as COM, MOI, and mass, allow for characterization of various weapons and allow for an easy comparison between weapon systems. Different weapons systems that have similar mass properties will behave similarly when exposed to similar dynamic conditions (such as aiming movements and weapon firing). Understanding the effects of manipulating the mass properties of a weapon will provide more information that can be generalized than can be obtained solely by a study of specific weapons.

---

[1]Winter, D. *Biomechanics and Motor Control of Human Movement (2nd ed.)*; New York: John Wiley and Sons, 1990.

[2]Hamill, J.; Knutzen, K. *Biomechanical Basis of Human Movement (first ed.)*; Baltimore: Williams & Wilkins, 1995.

[3]Zatsiorsky, V. *Kinetics of Human Motion (first ed.)*; Champaign, IL: Human Kinetics, 2002.

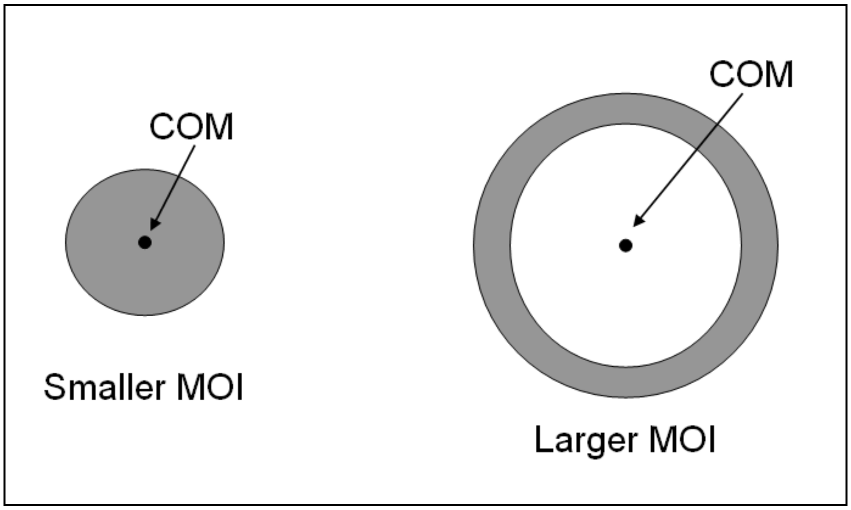


Figure 1. Two objects with similar locations of COM (i.e., the center of the object). (Because of different distributions of mass, these objects have vastly different MOIs.)

The U.S. Army Research Laboratory's (ARL's) Human Research Engineering Directorate is investigating the effect of three different weapon weights and the effect of manipulating the COM of the weapon to three different vertical positions. In subsequent research that will augment the U.S. Army effort, the Canadian Army will examine the effects of three different weapon weights and three different horizontal COM (fore and aft) locations on shooting performance. This report documents a software tool that was designed to support these studies by allowing researchers the ability to easily determine mass properties of a weapon system. The tool presents a photograph of the weapon and allows the user to place weight anywhere on the weapon by clicking on the screen. After the weight is placed, the software returns the mass properties of the weapon, including the effects of the added weight.

One use of this tool is to determine where to place weight on the weapon to obtain specific mass properties. This would be useful for experimental design of a study of the effects of mass properties, such as ARL's weapon aiming study.[4] Using the tool in this manner allows the user to manipulate the location and magnitude of mass added to the weapon; the tool will produce output that includes COM location and MOI based on the mass properties of the weapon (with no added weight) and the location and magnitude of the added weight. The user will be able to easily determine where to place weight on the weapon in order to achieve specific mass properties suitable for the experimental design.

Another use of this tool is to determine the effect of adding accoutrements (e.g., weapon systems, scopes, etc.) to a weapon on the mass properties of the overall system. Given the mass

[4]Harper, W.; LaFiandra, M.; Ortega, S. *The Effect of Weapon Weight and Balance on Shooting Performance with an Assault Rifle*; ARL HRED Protocol 20098-07036; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2007.

properties of the unweighted system and the mass and location of the added components, the user can place these objects on the picture of the weapon and the software will output the resulting mass properties of the weapon system including the accoutrements.

## 2. Objectives

The objective of this project was to develop an interactive tool for displaying and quantifying the mass properties of a weapon system based on the mass, COM location, and MOI of the weapon, and the mass and location of added accoutrements. A secondary objective was to produce an easy-to-use graphical user interface (GUI) for implementing the tool.

## 3. Equipment

The tool is software custom written in the MATLAB* (version 7.1.0 R14) programming language.

## 4. Methods

There are two parts of the tool. One part is the underlying software algorithms that perform the calculations and determine the mass properties based on user input. The other part is the GUI designed to allow input from the user and to display output. Each part of the software is described in detail in the following sections.

### 4.1 Software Algorithms for Calculating Mass Properties

The determination of COM location for an object can be calculated with equation 1[1,2]

General form of COM equation:

$$COM_x = \frac{1}{M}\sum_{i=1}^{n} m_i x_i \quad , \tag{1}$$

in which $COM_x$ is the location of the COM of the object along the object's x axis, $M$ is the total mass object (including the mass of all the segments), $n$ is the number of segments that comprise the object, $m_i$ is the mass of segment $i$, and $x_i$ is the location of the COM of segment $i$ in along the object's x axis. Equation 1 is a general equation that can be used to figure the COM of any

*MATLAB is a registered trademark of The MathWorks.

object that has multiple segments.  The software is designed to include as many as four segments (accoutrements) added to the weapon.  The specific form of the equation used for this analysis is presented in equation 2.

COM equation used to calculate weapon COM along x axis: $$COM_x = \frac{m_w x_w + \sum_{i=1}^{4} m_i x_i}{m_w + \sum_{i=1}^{4} m_i} \quad , \qquad (2)$$

in which $COM_x$ is the location of the composite COM of the weapon (including any accoutrements) along the weapon's x axis (see figure 2 for axes orientation), $m_w$ is the mass of the weapon, $x_w$ is the location of the weapon's COM (when there are no accoutrements), $m_i$ is the mass of object $i$, and $x_i$ is the location of the COM of object $i$ along the weapon's x axis.  As written in equation 2, the software is set up to calculate the COM of a weapon plus as many as four accoutrements.

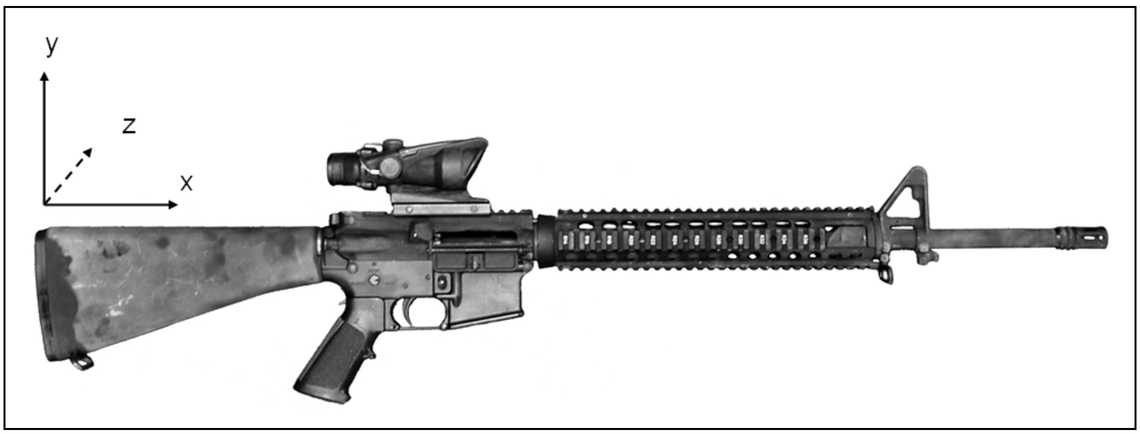


Figure 2.  Weapon showing orientation of axes.

Essentially, the same equation is used to calculate the COM of the weapon along its y and z axis (equation 3).

COM equation used to calculate weapon COM along y axis: $$COM_y = \frac{m_w y_w + \sum_{i=1}^{4} m_i y_i}{m_w + \sum_{i=1}^{4} m_i} \quad , \qquad (3)$$

in which $COM_y$ is the location of the composite COM of the weapon (including any accoutrements) along the weapon's y axis, $y_w$ is the location of the weapon's COM (when there are no accoutrements), and $y_i$ is the location of the COM of object $i$ along the weapon's y axis.  Many weapons are designed to be somewhat symmetrical along the Z axis, so the software is not currently set up to calculate COM along the Z axis but could easily be made to do so with equation 4.

COM equation that can be used to calculate weapon COM along z axis: $COM_z = \dfrac{m_w z_w + \sum_{i=1}^{4} m_i z_i}{m_w + \sum_{i=1}^{4} m_i}$ , (4)

in which $COM_z$ is the location of the COM of the object along the weapon's z axis, $z_w$ is the location of the weapon's COM (when there are no accoutrements), and $z_i$ is the location of the COM of object $i$ in along the weapon's z axis.

In order to calculate the MOI of the weapon plus any accoutrements, knowledge of the MOI of the weapon without accoutrements is needed. In the model, each accoutrement is considered a point mass on the weapon, meaning the mass of the accoutrement is concentrated in one place and the MOI of the accoutrement is neglected for this calculation.

The relationship between the MOI of an object about its COM and about any other axis of rotation can be determined via the parallel axis theorem shown in equation 5[1]

General form of the parallel axis theorem: $MOI_{new} = MOI_{com} + md^2$ , (5)

in which $MOI_{com}$ is the MOI about the COM, $m$ is the mass of the object and d is the distance between the object's COM and the axis of rotation.

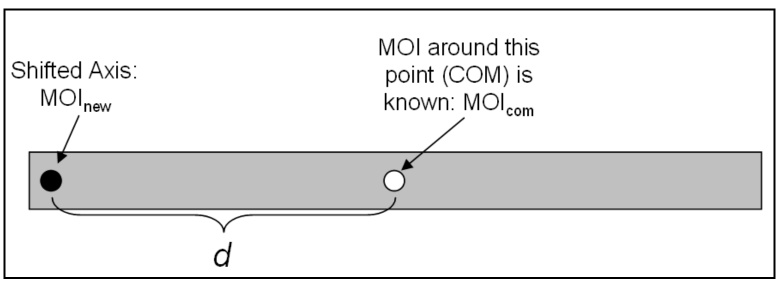


Figure 3. Diagram showing parallel axis theorem parameters.

The software determines the MOI of the weapon plus any accoutrements around the weapon's COM with the use of equation 6.

MOI of weapon about composite COM (includes effects of accoutrements):

$$MOI_{comp\_com} = MOI_{weap\_com} + m_{weap} d_{weap\_comp}{}^2 + \sum_{i=1}^{4} \left( m_i d_{i\_com}^2 \right) , \qquad (6)$$

in which $MOI_{comp\_com}$ represents the MOI of the weapon around the composite COM (which includes influence of accoutrements on COM), $MOI_{weap\_com}$ is the pre-determined MOI of the weapon around the weapon's COM (that does not include influence of accoutrements), $m_{weap}$ is the mass of the weapon (without any accoutrements), $d_{weap\_com}$ is the distance between the COM of the weapon (with no accoutrements) and the composite COM of weapon + accoutrements, $m_i$ is the mass of accoutrement $i$, and $d_{i\_comp}$ is the distance between the COM of accoutrement $i$ and the composite COM of the weapon plus accoutrements.

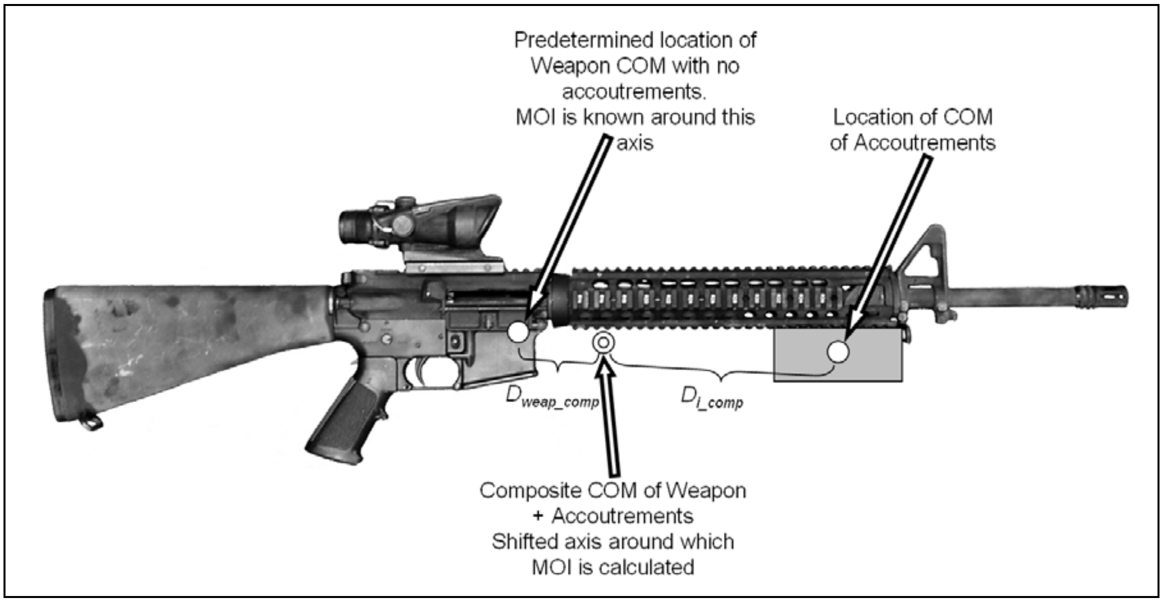


Figure 4. Diagram showing distances used for calculating MOI around composite COM.

## 4.2 Graphical User Interface

The GUI was designed to allow users to choose from a list of weapons. It is currently set up for two weapons, the M16A2 and the M4. When the software is running, the first screen that is presented is a dialogue box (figure 5). In this screen, the user simply double clicks the weapon s/he wants to add mass to; as more weapons are studied, the list can be updated.

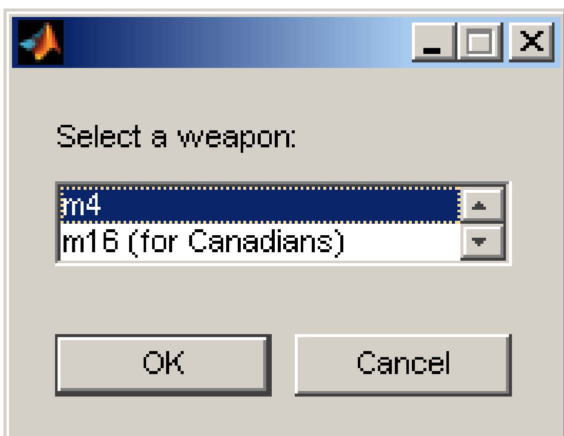


Figure 5. Weapon selection screen.

After the user clicks **OK** or double clicks the weapon s/he wants to analyze, the analysis window (figure 6) opens. This is the main window used for placing weights on the weapon. The window has three main areas: the picture of the weapon, the input area (bottom-left side of the window), and the output area (the bottom-right side of the screen).

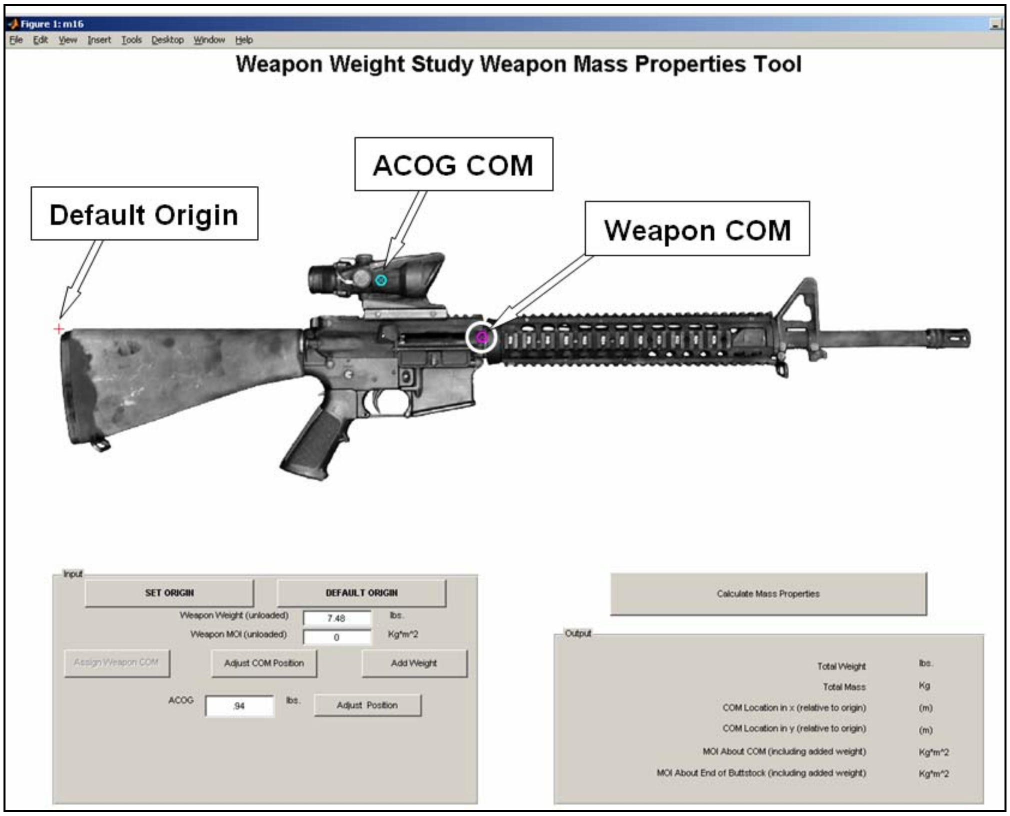


Figure 6. Weapon mass properties analysis window.

When the M16 is selected, figure 6 is presented. The default weight of the M16 with no magazine is 7.48 lb. Different variants of the weapon may have slightly different weights. The weight varies from the default; users may change the weight on the input area of the screen. The MOI of the weapon was not known, so the value has a default of 0 kgi·m$^2$. The default location of the COM of this weapon (with no accoutrements) was determined via a balance-board method[1] and is shown in figure 6 as a purple circle and x. Because the location of the COM of the M16 was known, the **Assign Weapon COM** button is inactive. This button is active for weapons that the COM was not known at the time the software was written. If the location of the COM of the weapon with no accoutrements needs to be moved for some reason, click **Adjust COM Position**, and click on the new location of the Weapon COM.

The M16 shown in figure 6 has the advanced combat optical gunsight (ACOG) already on it. The ACOG weighs 0.94 lb. The COM of the ACOG is assumed to be in the geometric center of the sight (shown as a turquoise circle and x in figure 6). If the ACOG is not part of the weapon system the user is interested in, the COM can be set to anywhere on the screen and the weight can be set to anything to represent any other accoutrements. Alternatively, the mass for this segment can be set to 0 and the ACOG will have no effect on the composite COM or MOI.

In figure 6, the origin is marked by a red cross with a white background and is in the default origin position—the top of the weapon's butt stock. The origin is the x = 0 and y = 0 position, and is the point from where the COM location is determined.  Many times, a user may be interested in determining the location of the COM from various other reference points.  For instance, the user may be interested in knowing the effect adding a piece of equipment has on the COM of the weapon relative to the COM of the weapon with no equipment on.  To do this, the user would click the **SET ORIGIN** button in the input area.

When the **SET ORIGIN** button is pressed, the mouse position is highlighted with cross hairs, and the (x,y) coordinates of the mouse position (in meters, scaled to the size of the weapon) is presented in the lower left corner of the screen, just above the input area of the window (figure 7).

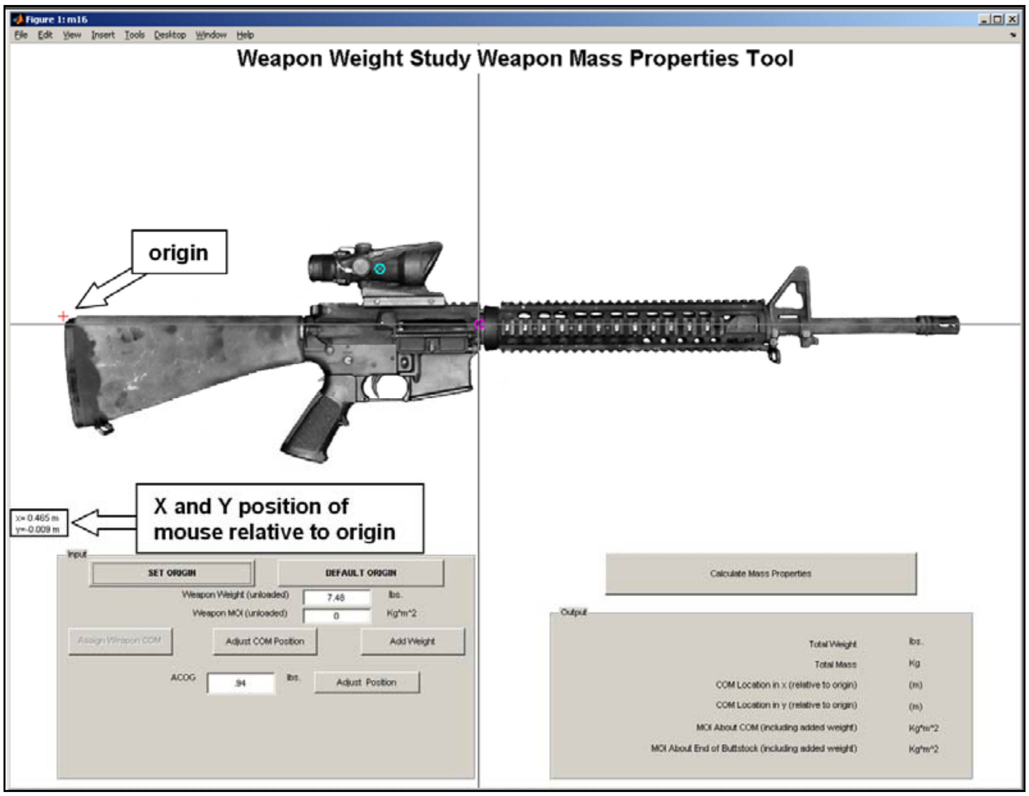


Figure 7.  Cross hairs showing location of the mouse pointer.

When the cross hairs are over the desired position of the origin, the user simply clicks the mouse, and the origin is moved (figure 8), and the (x,y) coordinates in the bottom left of the screen now show the distance the origin was moved.  Note that the red cross with the white background is now coincidental with where the user clicked, and this is now the (0,0) point.  To bring the origin back to the default position, the user clicks the **DEFAULT ORIGIN** button.

To add a weight to the weapon, the user would click the **Add Weight** button in the input area. As many as four weights can be added, including the ACOG (for the M16).  When the **Add Weight** button is pushed, a new set of cross hairs is presented, and the user clicks where s/he wants the weight to be added.  The (x,y) coordinates indicate the distance between the center of the cross hairs and the origin.  After the user clicks where s/he wants the weight to be added, another turquoise circle and x appear on the weapon, marking where the weight has been placed. Also, a data-entry box appears in the input area allowing the user to enter the weight (in pounds) of the added weight. If the weight was placed in the incorrect location, the user can click the **Adjust Position** button. When this is done, the weight that is being moved changes in color from turquoise to green, a new set of cross hairs appears, and the user can relocate the weight.

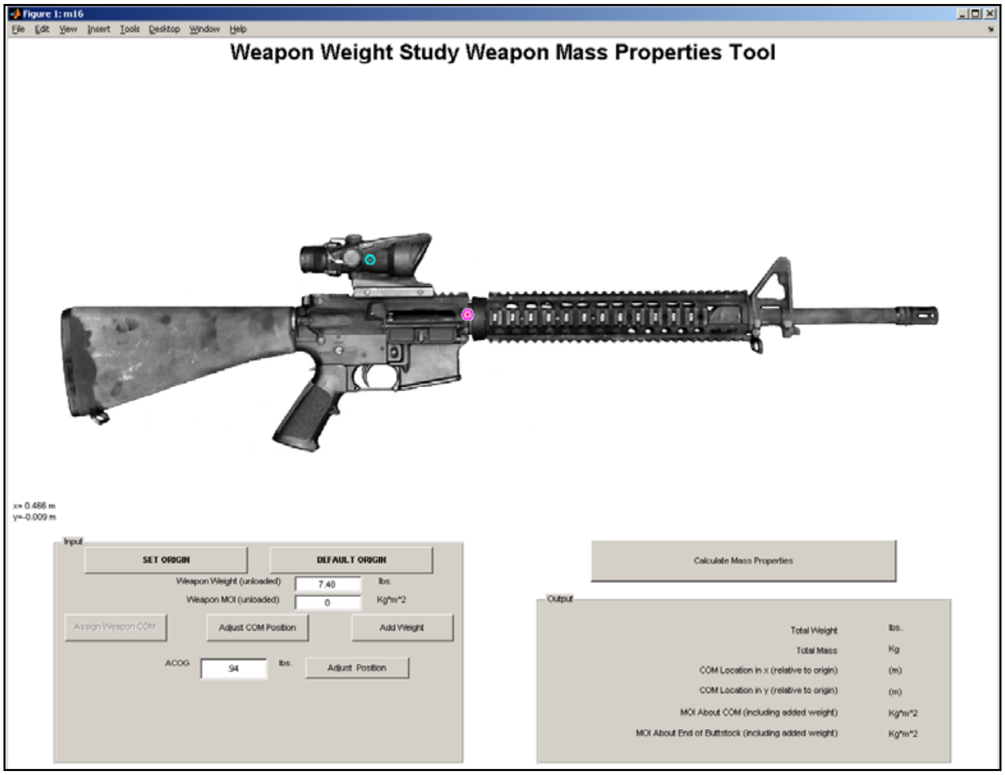


Figure 8. Screen showing origin moved.

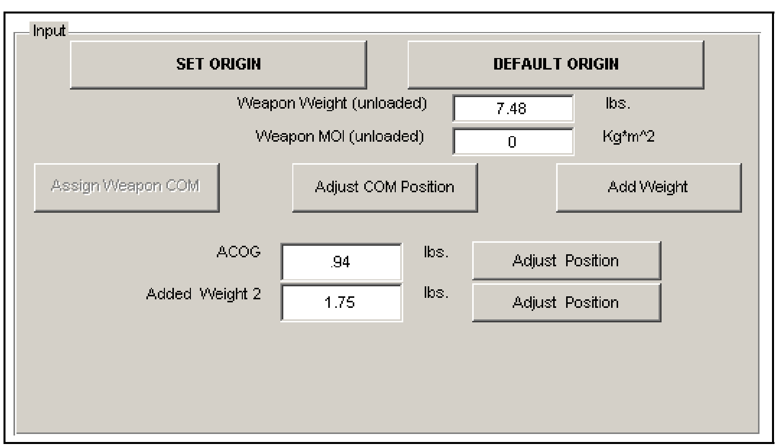


Figure 9. Input area of analysis window showing data entry box for **Added Weight 2**.

After all the weight locations are assigned, the user clicks the **Calculate Mass Properties** button, and the output is presented (figure 10). The turquoise circles and x's indicate the locations of the added weights. The purple x and circle indicate the location of the weapon COM (without any added weights). After clicking the **Calculate Mass Properties** button, a red circle on a white background appears, graphically indicating the location of the composite COM. $COM_x$ and $COM_y$ are determined via equations 2 and 3, respectively. The values in the output area of the window are updated. The total weight of the weapon system was determined to be the sum of weight of each of the components (including the weapon). The total mass of the system (in kilograms) is the weight times the proper conversion factor (1 lb = 0.45359 kg). The location of the composite COM (relative to the origin) is indicated numerically, and the MOI is presented relative to the COM and relative to the end of the butt stock. The end of the butt stock was chosen because it most proximal to the Soldier when the weapon is fired.

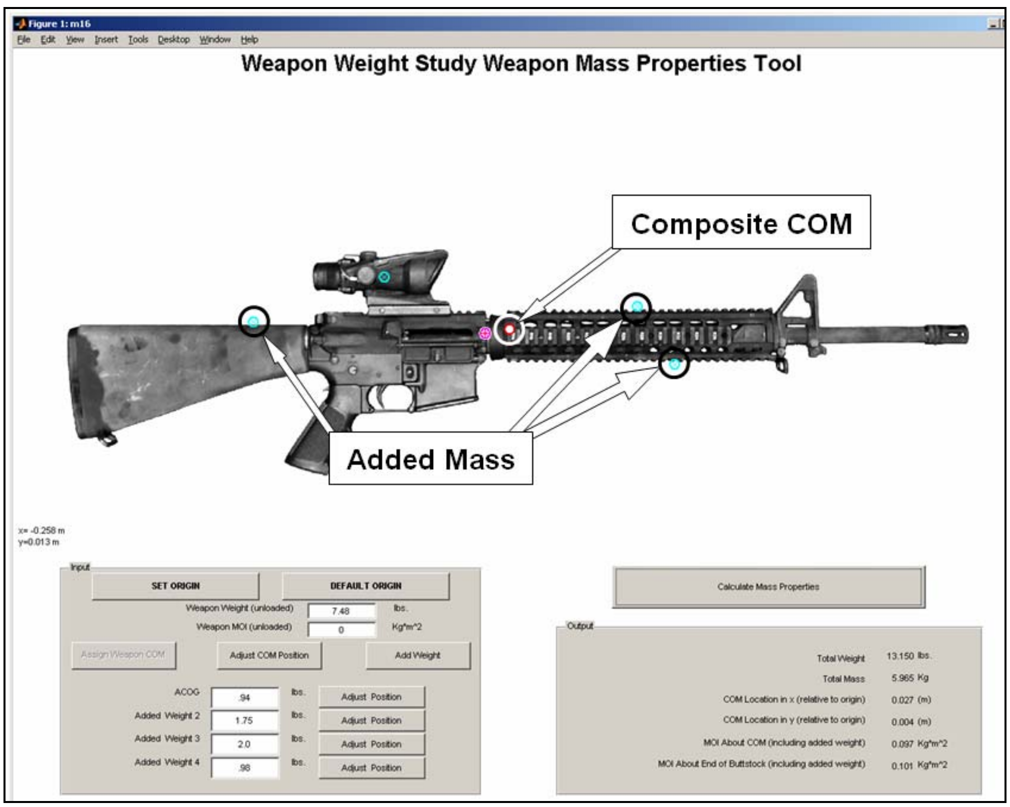


Figure 10. Output area of analysis window.

In the example given, the weight of the ACOG was entered as 0.94 lb. If the ACOG is not part of the weapon system being tested, the value for the ACOG weight can be set to 0 when one is calculating mass properties. Setting the weight of the ACOG to 0 will remove the effect of the ACOG on the mass properties.

At the completion of the analysis, the user can print the window to have a record of the results.

## 4.3 Sample Analysis

For this analysis, an M16 will be used and two weights will be added to the barrel of the weapon. To illustrate the effect of adding weight to the end of the barrel, the COM will be calculated after each of the two weights is added. Also, the ACOG will not be included in the analysis.

In the first window (see figure 5), choose M16 (for Canadians) from the list. The second window (figure 6) will be presented. Assign the weight for the ACOG to 0 (figure 11).

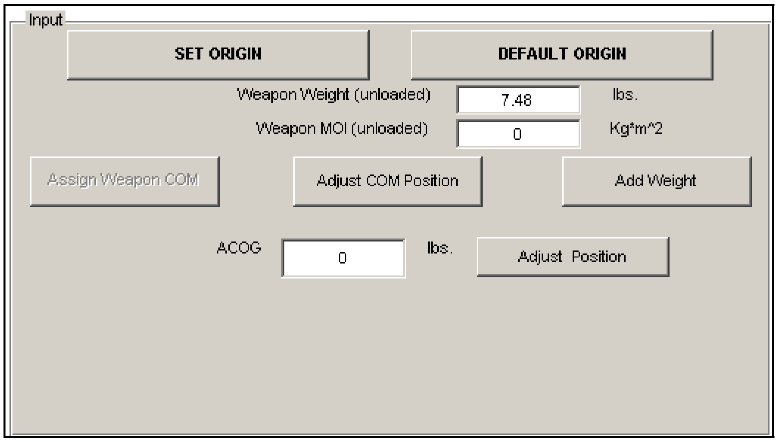


Figure 11. Input area with ACOG weight set to zero.

Click **Add Weight** to add the first mass. The cross hairs will appear. Click on the weapon in the location where the weight will be added (figure 12).

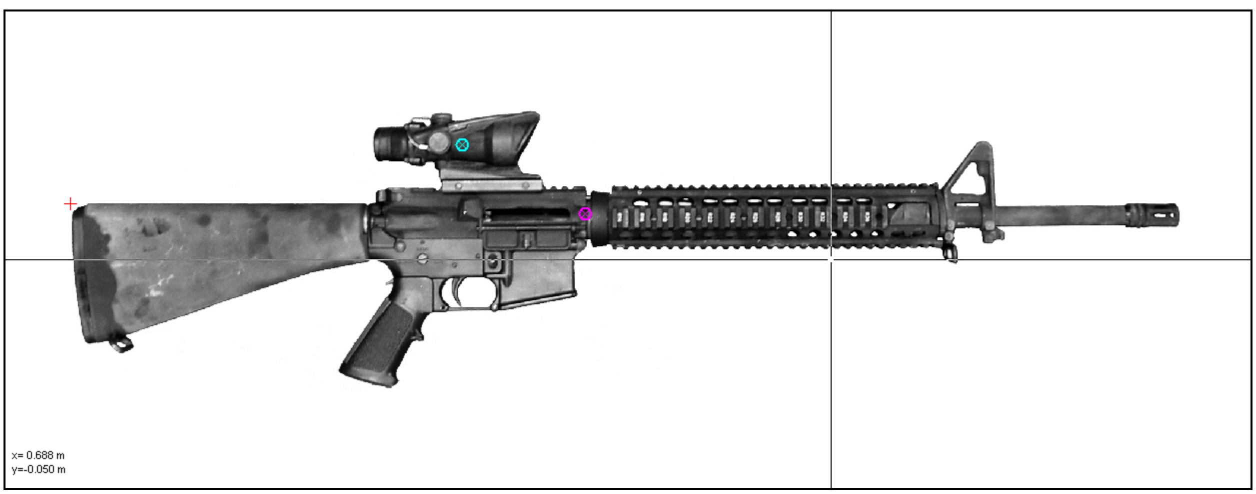


Figure 12. Weapon with cross hairs.

Set the weight for this item to be 3.27 lb (figure 13).

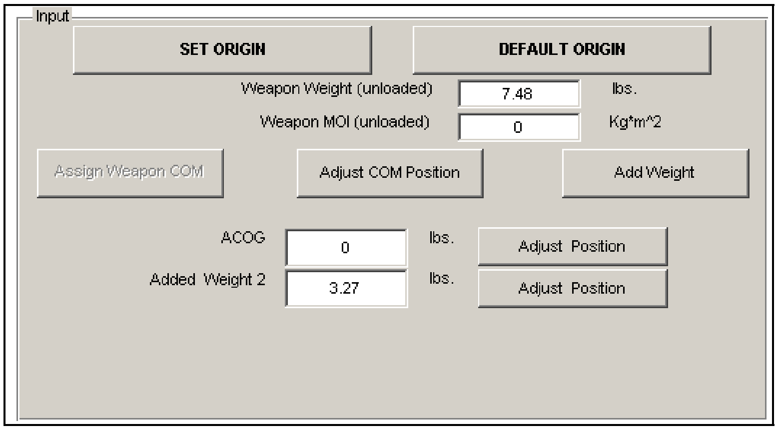


Figure 13. Input area with **Added Weight 2** set to 3.27 lb.

Click **Calculate Mass Properties** to calculate the effect of **Added Mass 2** on the mass properties of the weapon (figure 14). Note that the origin was left in the default location (top, back of butt stock). The composite COM of the weapon and **Added Mass 2** is 0.531 m from the origin along the x axis (which is parallel to the barrel of the weapon) and 0.001 m above the origin along the y axis. The location of the composite COM is shown in figure 14 as a red circle.

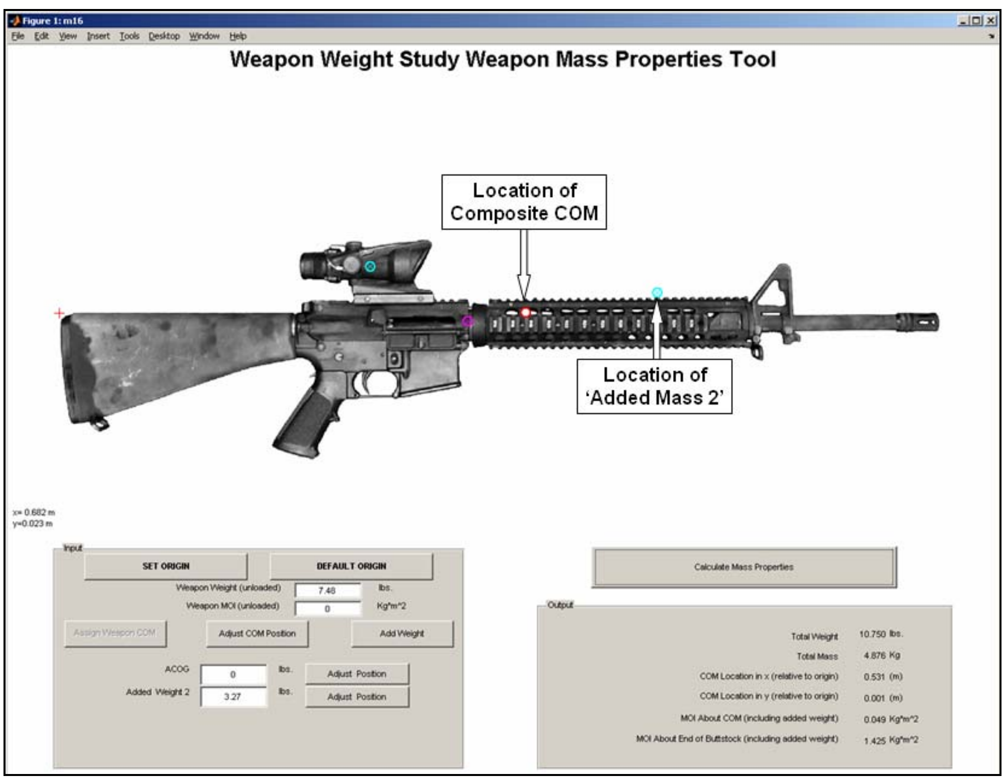


Figure 14. Output including effect of **Added Mass 2**, default origin.

Click **Adjust Position** next to the **Added Weight 2**. The cross hairs will appear, and set the location of the added weight closer to the end of the barrel. Click **Calculate Mass Properties** again, and note that the composite COM has moved (figure 15). With the new location of **Added Mass 2**, the composite COM is now 0.599 m from the origin along the x axis and is still 0.001 m above the origin.

Click **Add Weight** to add another weight (**Added Mass 3**) to the weapon. Add this weight under the weapon, and set the weight to 4.60 lb. Click **Calculate Mass Properties** to determine the effect of adding **Added Mass 3** on the mass properties of the weapon (figure 16). Note that the new location of the composite COM is 0.57 0 m from the origin along the X axis, and the composite COM is now –0.030 m from the origin along the y axis (0.030 m below the origin).

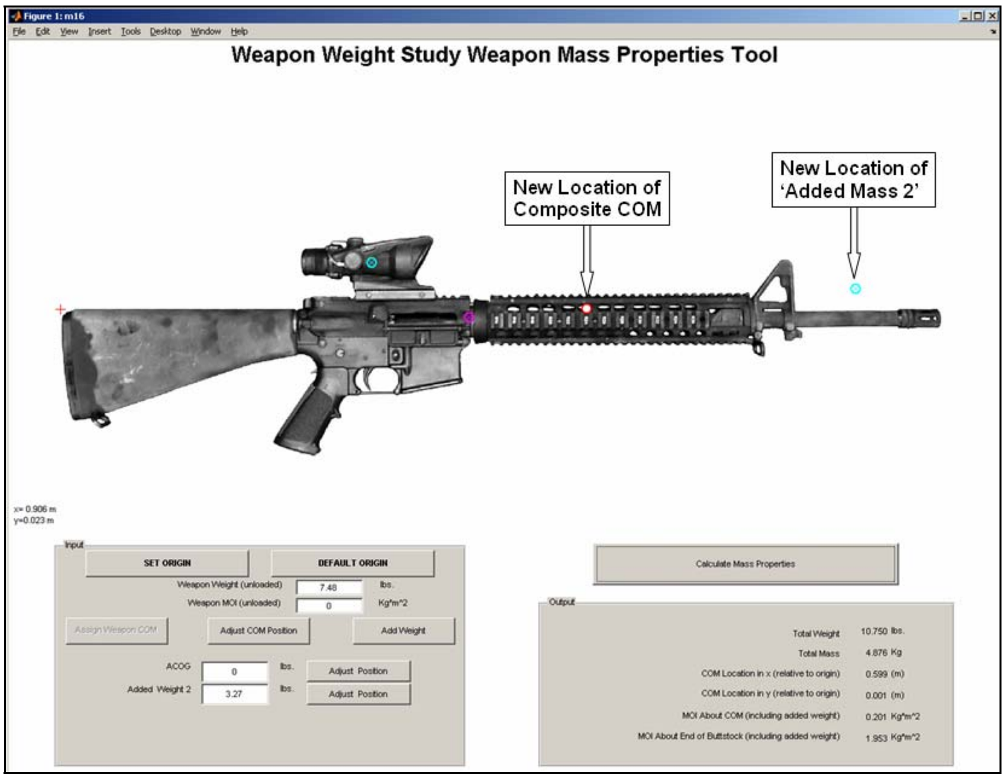


Figure 15. Output with **Added Mass 2** moved.

The composite COM coordinates in the output are relative to the origin, which in this example is at the top and end of the butt stock (depicted with a red cross). Many times, it is necessary to know the composite COM coordinates relative to the COM of the weapon with no accoutrements. Clicking **SET ORIGIN** will allow the user to change the location of the origin. After the origin is set to be the COM of the weapon with no accoutrements (depicted by a purple circle and x), clicking **Calculate Mass Properties** will figure the distance between the COM of the weapon with no accoutrements and the composite COM of the weapon with all of the added weight (figure 17). While the location of the composite COM did not change when the origin was moved, the output window has updated values showing the distance between the origin and the composite COM. Because the origin and the COM of the weapon with no accoutrements are coincidental in space, the output window indicates the distance between the COM of the weapon with no accoutrements and the composite COM, which is 0.104 m along the x axis, and –0.021 m along the y axis.  Note that the MOI is not accurate in this example because the **Weapon MOI** in the input window is set to 0.

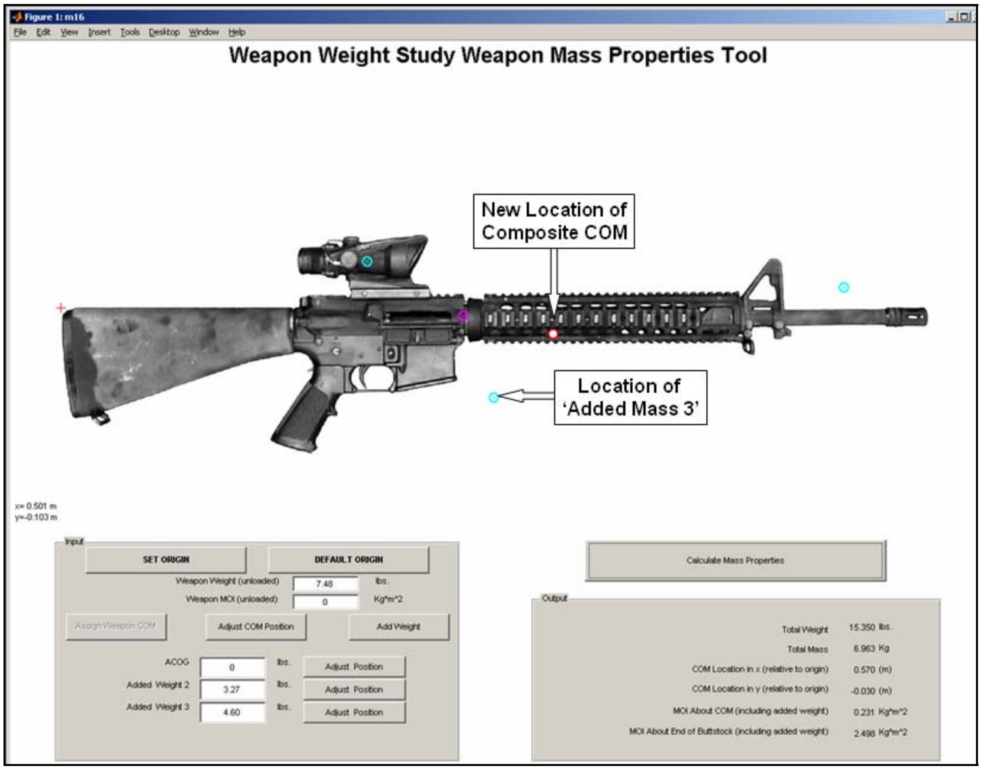


Figure 16.  Output with **Added Mass 3**.

## 5.   Concluding Remarks

The current report describes and demonstrates the use of a software tool designed to calculate the effect of weight added to a weapon on the weapon's mass properties (COM, MOI, and total mass).  The Weapon COM Tool is based on fundamental equations found in many physics or biomechanics texts[1,2] and can determine the effects of as many as four added weights.  The added weight can be accoutrements (such as new sights), additional weapons (such as an M203 grenade launcher), or any other object that is mounted to the weapon.

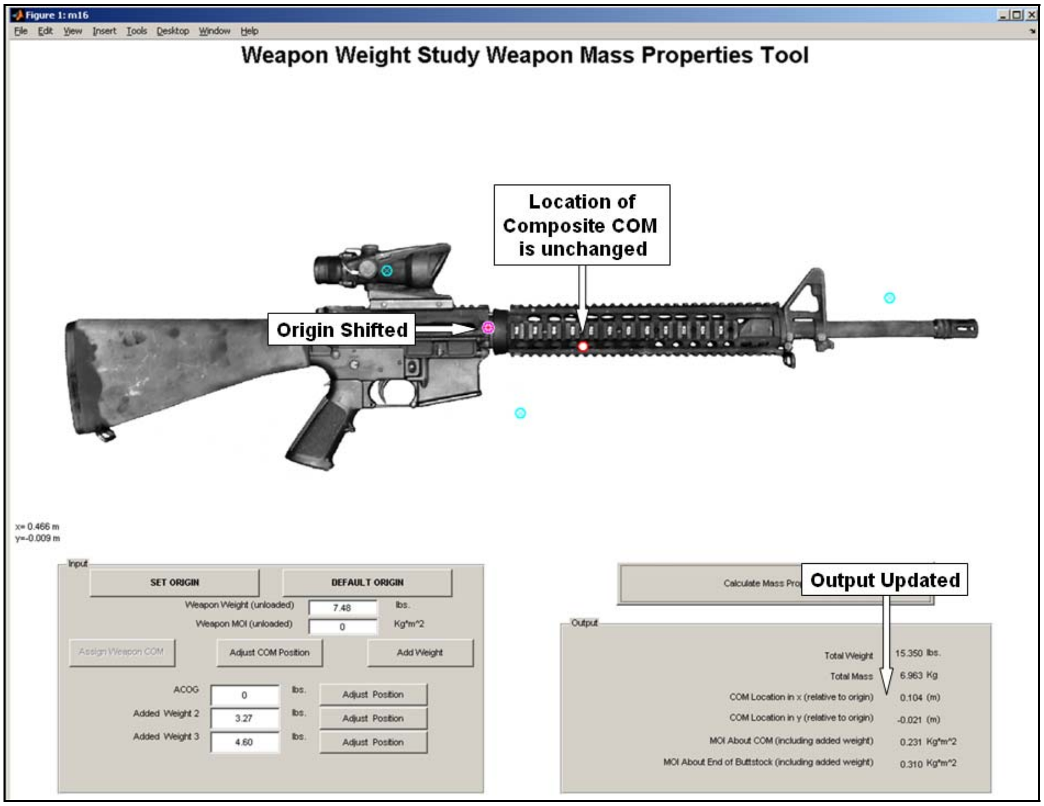


Figure 17. Output with origin aligned with unweighted weapon.

| NO. OF COPIES | ORGANIZATION |
|---|---|
| 1 (PDF only) | DEFENSE TECHNICAL INFORMATION CTR<br>DTIC OCA<br>8725 JOHN J KINGMAN RD<br>STE 0944<br>FORT BELVOIR VA 22060-6218 |
| 1 | US ARMY RSRCH DEV & ENGRG CMD<br>SYSTEMS OF SYSTEMS INTEGRATION<br>AMSRD SS T<br>6000 6TH ST STE 100<br>FORT BELVOIR VA 22060-5608 |
| 1 | DIRECTOR<br>US ARMY RESEARCH LAB<br>IMNE ALC IMS<br>2800 POWDER MILL RD<br>ADELPHI MD 20783-1197 |
| 1 | DIRECTOR<br>US ARMY RESEARCH LAB<br>AMSRD ARL CI OK TL<br>2800 POWDER MILL RD<br>ADELPHI MD 20783-1197 |
| 1 | DIRECTOR<br>US ARMY RESEARCH LAB<br>AMSRD ARL CI OK T<br>2800 POWDER MILL RD<br>ADELPHI MD 20783-1197 |

ABERDEEN PROVING GROUND

| | |
|---|---|
| 1 | DIR USARL<br>AMSRD ARL CI OK TP (BLDG 4600) |

NO. OF
COPIES ORGANIZATION

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR ML J MARTIN
MYER CENTER RM 2D311
FT MONMOUTH NJ 07703-5601

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MZ A DAVISON
320 MANSCEN LOOP STE 115
FT LEONARD WOOD MO 65473

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MD T COOK
BLDG 5400 RM C242
REDSTONE ARSENAL AL 35898-7290

1 COMMANDANT USAADASCH
ATSA CD
AMSRD ARL HR ME DR HAWLEY
5800 CARTER RD
FT BLISS TX 79916-3802

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MM DR V J RICE
BLDG 4011 RM 217
1750 GREELEY RD
FT SAM HOUSTON TX 78234-5002

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MG R SPINE
BLDG 333
PICATINNY ARSENAL NJ 07806-5000

1 ARL HRED ARMC FLD ELMT
AMSRD ARL HR MH C BURNS
BLDG 1467B RM 336
THIRD AVE
FT KNOX KY 40121

1 ARMY RSCH LABORATORY - HRED
AWC FIELD ELEMENT
AMSRD ARL HR MJ D DURBIN
BLDG 4506 (DCD) RM 107
FT RUCKER AL 36362-5000

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MK MR J REINHART
10125 KINGMAN RD
FT BELVOIR VA 22060-5828

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MV HQ USAOTC
S MIDDLEBROOKS
91012 STATION AVE RM 348
FT HOOD TX 76544-5073

NO. OF
COPIES ORGANIZATION

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MY M BARNES
2520 HEALY AVE
STE 1172 BLDG 51005
FT HUACHUCA AZ 85613-7069

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MP D UNGVARSKY
POPE HALL BLDG 4709
BCBL 806 HARRISON DR
FT LEAVENWORTH KS 66027-2302

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MJF J HANSBERGER
JFCOM JOINT EXPERIMENTATION J9
JOINT FUTURES LAB
115 LAKEVIEW PKWY STE B
SUFFOLK VA 23435

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MQ M R FLETCHER
US ARMY SBCCOM
NATICK SOLDIER CTR
AMSRD NSC WS E BLDG 3 RM 343
NATICK MA 01760-5020

1 ARMY RSCH LABORATORY-HRED
AMSRD ARL HR MT J CHEN
12423 RESEARCH PKWY
ORLANDO FL 32826

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MT C KORTENHAUS
12350 RESEARCH PKWY
ORLANDO FL 32826

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MS C MANASCO
SIGNAL TOWERS
BLDG 29808A RM 303
FT GORDON GA 30905-5233

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MU M SINGAPORE
6501 E 11 MILE RD MS 284
BLDG 200A 2ND FL RM 2104
WARREN MI 48397-5000

1 ARMY RSCH LABORATORY - HRED
AMSRD ARL HR MF C HERNANDEZ
2421 NW AUSTIN RD STE 220
FT SILL OK 73503-9042

| NO. OF COPIES | ORGANIZATION |
|---|---|
| 1 | ARMY RSCH LABORATORY - HRED<br>AMSRD ARL HR MW  E REDDEN<br>BLDG 4  ROOM 332<br>FT BENNING GA  31905-5400 |
| 1 | ARMY RSCH LABORATORY - HRED<br>AMSRD ARL HR MN  R SPENCER<br>DCSFDI HF<br>HQ USASOC BLDG E2929<br>FT BRAGG NC   28310-5000 |
| 1 | ARMY G1<br>DAPE MR  B KNAPP<br>300 ARMY PENTAGON ROOM 2C489<br>WASHINGTON DC 20310-0300 |
| | ABERDEEN PROVING GROUND |
| 2 | DIR USARL<br>AMSRD ARL CI OK TP<br>S FOPPIANO<br>AMSRD ARL HR MR<br>F PARAGALLO |

| NO. OF <br> <u>COPIES</u> | <u>ORGANIZATION</u> |
|---|---|
| 5 | DIR USARL<br>AMSRD ARL HR MB<br>M LAFIANDRA |

INTENTIONALLY LEFT BLANK.